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"SLEEPABILITY" AND "WAKEABILITY" FOLLOWING SLEEP DEPRIVATION

Peretz Lavie
Faculty of Medicine
Technion, Israel Institute of Technology

for

Scientific Coordination Office, London
Michael Kaplan, Chief

BASIC RESEARCH LABORATORY
Milton R. Katz, Director

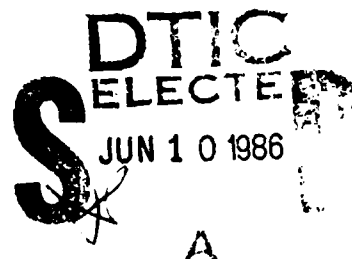


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May 1986

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARI Research Note 86-64	2. GOVT ACCESSION NO. AD A16578	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) "Sleepability" and "Wakeability" Following Sleep Deprivation		5. TYPE OF REPORT & PERIOD COVERED Final Report Period ending August 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Peretz Lavie		8. CONTRACT OR GRANT NUMBER(s) DAJA 37-81-C-0237
9. PERFORMING ORGANIZATION NAME AND ADDRESS Faculty of Medicine, Technion - Israel Institute of Technology Haifa, Israel		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q161102B74D
11. CONTROLLING OFFICE NAME AND ADDRESS U.S.A.R.D.S.G. (UK) Box 65 F.P.O. New York 09510		12. REPORT DATE May 1986
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) U.S. Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue, Alexandria, VA 22333-5600		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE - -
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) - -		
18. SUPPLEMENTARY NOTES Michael Kaplan, contracting officer's representative		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Sleep Deprivation Circadian Rythms, "Sleepability" Reaction Time Task, "Wakeability" ↳ Ultradian Rythms,		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) ↳ This research note discusses experiments investigating the infrastructure of arousal during the habitual waking day following one night of total sleep deprivation. Based on the data collected during the experiment, it can be concluded that "wakeability", the ability to remain awake, and "sleepability", the ability to fall asleep, following sleep deprivation, are not complimentary processes, but are probably governed by different mechanisms. The practical implications of these results to the scheduling of replacement naps are discussed. <i>Kun ends</i>		

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Introduction

The modern sophistication of weaponry systems demands from combatant personnel complex operations which require alertness, precision, fast information processing and quick decision making. Usually combat effort is concentrated in short time intervals during which there is continuous military activity. Key limiting factors for such continuous operation, beside unavoidable physical fatigue are accumulated sleep loss and naturally occurring rhythmic variations in performance. A large volume of research has demonstrated the operational consequences of sleep loss on various aspects of human performance (e.g., Johnson, 1969; Johnson & Naitoh, 1974; Naitoh, 1969). Decrement in performance because of sleep loss depends upon a complex interaction of factors such as the nature of the task, its meaning to the performer, and the level of the performer's motivation. Similarly the occurrence of natural rhythms in human performance, mostly with a periodicity of about 24 hours/cycle have been extensively studied and several books and symposia have been dedicated to this subject (Alluisi and Chiles, 1967; Colquhoun, 1971) Johnson, Topas, Colquhoun & Colligan, 1981).

Considerably less experimental effort has been addressed to the investigation of short term rhythms in human performance and their interaction with sleep loss, which have been the subject of research in our laboratory during the last few years. Detailed review of the existing knowledge on ultradian rhythms has just been published (Lavie, 1982). In a series of experiments carried out in the last two years, we have shown that in certain tasks there are reliable short term variations in efficiency, with periodicities centred around $1\frac{1}{2}$ hours. Such periodicities were clearly seen in the accuracy of motor performance in subjects tested every 20 or

10 minutes (Lavie, Gopher, Zomer & Fogel, 1981). One and a half hour rhythms in the flow of urine measured in the same subjects were not related to the rhythms in motor accuracy, suggesting that independent oscillators regulate body fluids balance (Gopher & Lavie, 1980; Lavie & Kripke, 1977). In contrast to the rhythmic variations in movement accuracy, the speed of movement did not show any rhythmicity, suggesting that the short term rhythms in performance do not reflect the activity of a general non-specific "arousal" rhythm which would be expected to affect speed as well as accuracy. Further support for this conclusion was provided by additional studies demonstrating lack of rhythmicity in a reaction time task and only weak traces of 1½ hour rhythmicity in a two-dimensional tracking task (Lavie, Gopher, Zomer & Fogel, 1981). Since the rhythmicity in movement accuracy was suppressed by immediate knowledge of results, we hypothesized, as will be discussed later, that the rhythmicity in accuracy reflected variations in the efficiency of short term memory storage processes, mediated by underlying 1½ hour rhythms in arousal processes.

Evidence for the existence of 1½ hour rhythmicity in arousal processes has been accumulated in several laboratories, including our own, over the last several years. Ultradian rhythms in electroencephalographic activity, particularly in the intensity of delta activity, typical of slow wave sleep, were demonstrated in isolated and sleep deprived subjects by Kripke (1972). Pupillary diameter and stability, traditional indices of arousal levels, were also shown to vary rhythmically with the same periodicity (Lavie, 1979). In an experiment just accomplished, as part of our three-year series of experiments, we demonstrated that the 1½ hour rhythmicity in physiological arousal is indeed reflected in rhythmic variations in the ability to fall asleep during the day (Lavie & Scherson,

1981). Subjects instructed to attempt to fall asleep every 20 min, for 12 continuous hours (that is a 12-hour schedule of 15 min wake - 5 min sleep) showed clusters of sleep stage 1 about every 1½ hours. Sleep stage 1 is a transitional stage between wake and sleep. Sleep stage 2, on the other hand, did not occur rhythmically, but showed a unimodal distribution with mid-afternoon peak around 1500 coinciding with the well-known "post lunch dip" in performance (Blake, 1967). Selective REM deprivation as well as total sleep deprivation modified the 1½ hour rhythms as well as the distribution of sleep stage 2. This effect of sleep deprivation on stage 2 was rather impressive. Following sleep deprivation, instead of a unimodal distribution of sleep stage 2, a bimodal distribution emerged with a mid-afternoon sleepiness peak and an additional mid-morning peak. These results have important theoretical and practical implications in view of the intensive investigation of the role of restorative naps in alleviating the effects of sleep deprivation on combatant personnel (Naitoh, 1981; Pinges, et al., 1981).

In light of these unexpected findings our research effort during 1981/82 was directed at investigating the influence of sleep deprivation on the ultradian rhythmicity in the ability to fall asleep during the day, and the interaction between these rhythms and performance.

Method and Design

Subjects:

Twelve subjects, aged 22 to 28, all veterans of combat units of the IDF, participated in the study. They were healthy, and with normal sleep-wake habits, as determined from two-week sleep diaries and from two nights pre-experimental whole-night polyhynographic sleep recordings.

Experimental Procedure:

- 1) Adaptation to the laboratory - each of the subjects spent two nights in the laboratory for adaptation purposes. Polyhypnographic recordings (EEG, EOG, EMG, and respiration to exclude breathing abnormalities in sleep) were obtained from 2300 until 0700, on the second night only.
- 2) Baseline - Subjects come to the laboratory at 2200, after a normal day without naps. Polyhypnographic recordings began at 2300 and continued until 0700 the next day, as during the adaptation night. The day-experiment began at 0720 and lasted for 16 consecutive hours.

From 0720, a precise 13 min - wake, 7 min - sleep schedule was begun, and was maintained for 48 consecutive 20-min periods (16 hours, until 2300). Every 13 min, subjects were instructed to lie in bed, close their eyes, and attempt to fall asleep. Polyhypnographic recordings (EEG, EOG, and EMG) were performed during the 7-min "sleep attempts". If subjects were asleep at the end of the 7-min period they were awakened, and the lights were turned on. The 13:7 wake-sleep schedule was chosen to approximate the normal 2:1 wake-sleep ratio (16 h. wake, 8 h. sleep).

During the 13-min scheduled wake time subjects were disconnected from the polygraph and were requested to leave the bedroom. At about the middle of the wake period they performed two tests: "Add 7" and a combined one-hand, and coordinated two-hands, reaction time task. In the first task subjects had to sum up as many pairs of 3 digit numbers and to add 7 to the sum, as they possibly could in 60 seconds.

The second task was one or two handed coordinated reaction time tasks. In this type of task, after a "go" signal, subjects simultaneously initiate two-handed movements to targets of disparate or equal difficulty and distance

(Kelsom Southard & Goodman, 1979). The apparatus consisted of a plexi-glas base (76 cm long, 16 cm wide and 2 cm thick), mounted on a standard table. Two contact switches, centred 0.5 cm apart served as the home keys (see Fig. 1 for a schematic representation of the apparatus). The four targets were positioned along the longitudinal center line of the base, two large targets (7 cm in diameter) at a distance of 22 cm from the home keys, and two small targets (3.5 cm in diameter) at a distance of 4 cm from the home keys. A single target was used in the one handed condition, and two targets were used in the two handed conditions. A red light emitting diode served as the warning signal, and similar diodes mounted above the targets served as the "go" signal and designated the targets. Stimuli presentation and data collection were controlled by a PDP 11/34 minicomputer.

Subject's task was to move his index finger from the home keys to the target as fast and as accurately as possible, after receiving the "go" signal above the appropriate target. The "go" signals were given 1 sec after the warning signal. Five combinations were presented in each 20 min session: 1) right hand "near" target 2) right hand "far" target 3) two handed "near" targets, 4) two handed "far" targets, and 5) right hand "far" combined with left hand "near" targets. Each of the combinations was presented 5 times with an average intertrial interval of 5 sec. The order of presentations was randomized and two practice trials, which were not included in the final analysis, were presented at the beginning of each session. If subject missed the target, that trial was excluded and another trial was presented by the computer.

In each trial, both reaction times (the time from the "go" signal to the release of the home keys) and movement times (the time from the release

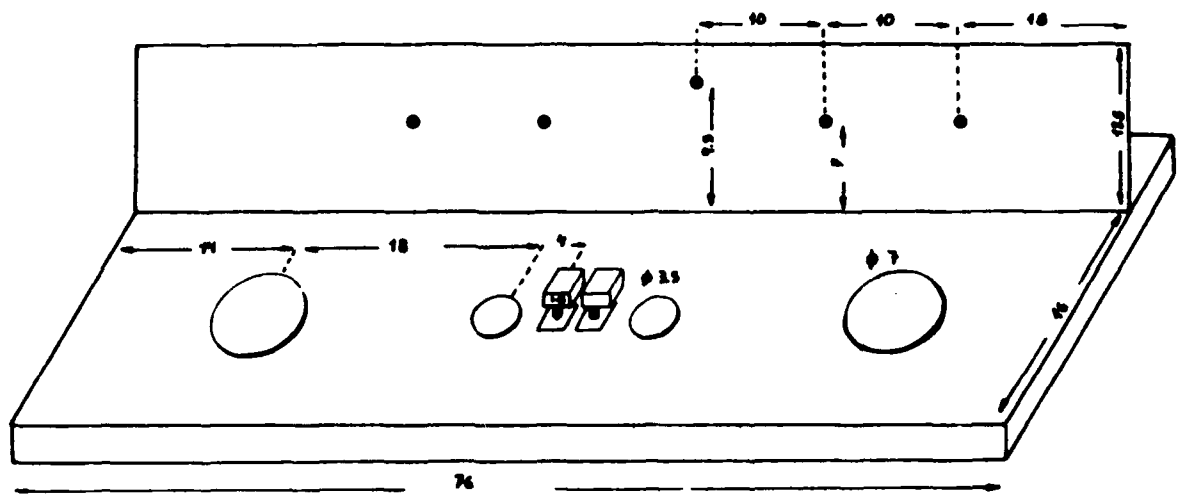


Fig. 1: Schematic representation of the one hand and two-handed reaction time apparatus.

of the home keys until reaching the targets) were registered by the computer. Reaction times greater than 800 msec or less than 90 msec, and movement times less than 30 msec or greater than 600 msec, were excluded from the final analysis.

From the 5 trials of each combination, mean reaction time and movement time were computed. Since there were two one-hand conditions and 3 two-handed conditions, there were 8 separate means for each session. Since, however, performance of the two hands were highly correlated across time, the number of data points could be reduced by averaging across experimental combinations.

3) Sleep Deprivation - "sleep" condition (SC)

In this part of the experiment subjects came to the laboratory at 2000, at least a week after the completion of the previous part of the experiment (e.g. the design was balanced across subjects in such a way that 6 subjects performed initially SC, and then RS, and 6 subjects were tested in the reverse order). They spent the night awake in the laboratory reading, listening to music, etc. under close observation of an experimenter. No polygraphic recordings were performed and food was available ad libitum. Then, at 0720 the experimental schedule of 13-min-wake, 7 min-sleep was initiated for 16 hours for 8 subjects.

As before, a monitored recovery sleep followed the experimental day. Behavioral testing was conducted during the 13 min scheduled wake periods. For the other 4 subjects the experimental schedule was continued for 24 consecutive hours until 0700 the next morning.

4) Sleep Deprivation - "Resist Sleep" Condition (RS)

In this part of the experiment subjects came to the laboratory at least one week after the completion of the previous part. They spent the night

awake in the laboratory from 2000 until 0720 as in SC. Then, at 0720, a precise experimental schedule of 13-min-wake outside the bedroom, 7 min awake in bed with eyes closed, was initiated for 16 hours, for 8 subjects. In this experimental condition, every 20 min subjects were instructed to enter the bedroom, to lie in bed and to close their eyes, and to try to remain awake for 7 min. At the end of the 7 min, if asleep, they were awakened, the lights were turned on, and they were instructed to enter the testing room, where they remained for the scheduled 13 min wake period. Polyhypnographic recordings were performed during the 7 min "in bed" periods. To increase subjects' motivation to resist sleep, extra monetary bonuses were promised for the three best performing subjects; e.g. the three subjects with the maximum amount of wake time.

Behavioral testing was conducted during the 13 min scheduled wake periods as before, and a polygraphically monitored recovery sleep followed the 16 h experimental period. As in the SC experiment, for 4 subjects the experimental schedule was continued for 24 consecutive hours until 0700 the next morning.

Results

Temporal structure of "sleepability" and "wakeability" - Fig. 2 presents the mean histograms of total sleep (stage 1 + stage 2 + stages 3 & 4 + stage REM) per 7 min (in percentages) in each of the 3 experimental conditions: baseline, SC and RS, for the 8 subjects tested for 16 hours (from 0720 until 2300). Obviously, under both sleep deprivation experiments total sleep during the day was considerably higher than during baseline. There was no significant difference, however, between the amounts of sleep stage 1 and 2 in the two experiments (see Table 1). (Overall means of stage 1 and stage 2 for those 8 subjects were 26.38% and 18.9%). In spite of the similarity in the overall means, there was, however, a clear phase difference between the two mean curves. The mean curve for the SC experiment peaked at 0800 and then five hours later at 1300, while the mean curve for the RS experiment peaked an hour later at 0900 and then at 1420. That is, although in both conditions the interpeak interval was 5 hours, the peaks were delayed by about one hour when subjects attempted to remain awake rather than to fall asleep. Under both conditions, sleep decreased toward the evening hours, reaching a minimum at 18-1900.

Ten frequencies spectral analysis confirm the eye ball analysis. Fig. 3 presents the average spectra for stage 1 and stage 2 in the baseline, SC and RS experiments. The average spectra for stage 1 in the baseline experiment peaked at the fast ultradian frequencies of 21.6 and 25.6 c/day, corresponding to periodicities of about 67 to 57 min/cycle. This spectral peak however was not statistically significant. In the SC and RS experiments, average spectra for stage 1 peak at the slow ultradian

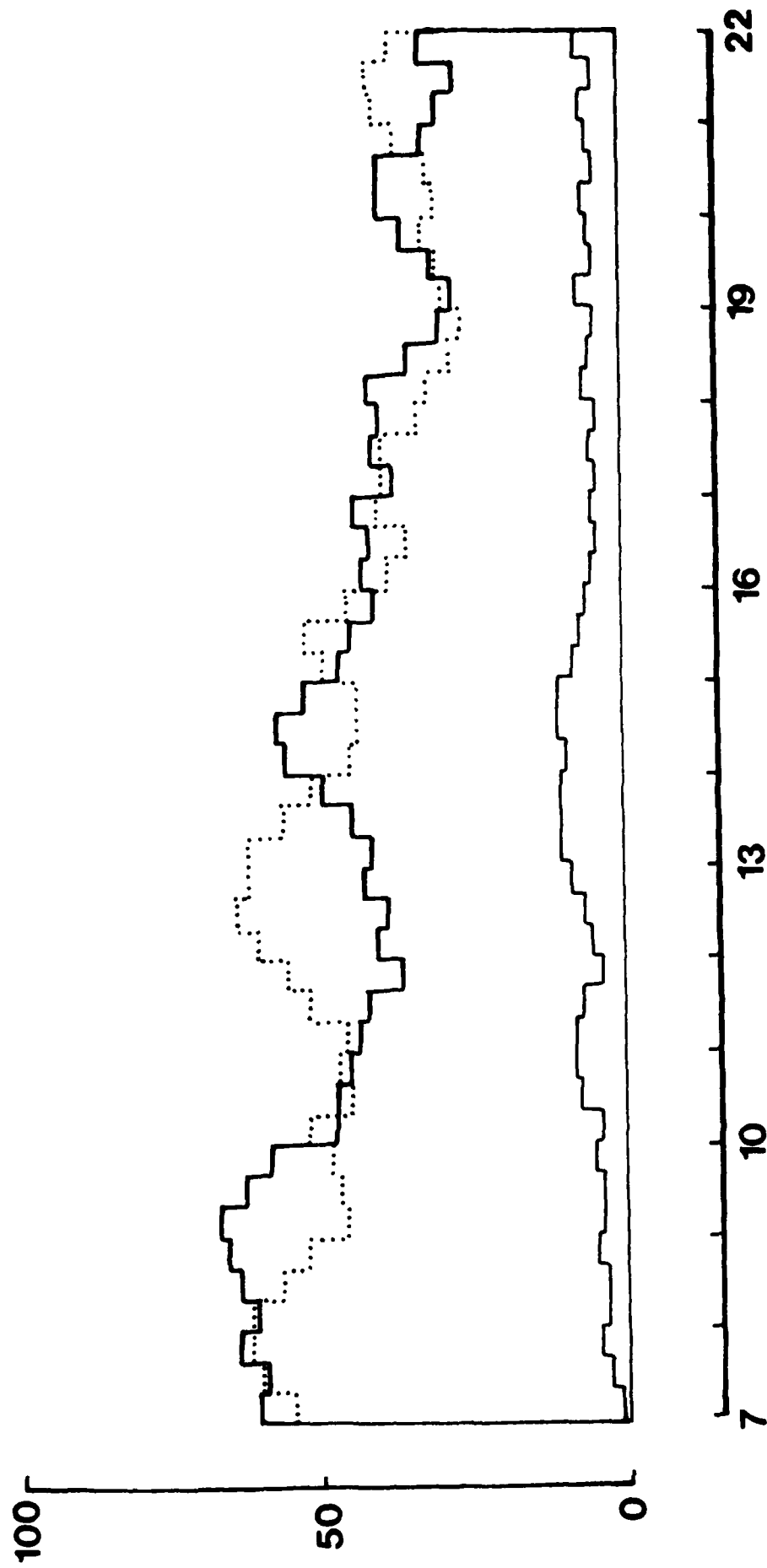


Fig. 2: Mean histogram of total sleep / 7 min, for baseline (—), sleep deprivation with sleep (.....) and sleep deprivation without sleep (—)

<u>Stage 1</u>						
<u>Subject</u>	<u>Percentages</u>			<u>Occurrences</u>		
	<u>BL</u>	<u>RS</u>	<u>SC</u>	<u>BL</u>	<u>RS</u>	<u>SC</u>
Avi.	1.51	21.21	34.7	6	29	40
Gid.	2.42	17.07	15.08	8	41	45
Ami.	9.7	16.44	23.1	31	42	47
Dan.	9.3	40.23	25.95	29	46	47
Ari.	3.02	22.37	15.17	14	45	35
Dav.	4.91	31.93	30.1	19	43	45
Ehu.	3.75	38.47	21.77	1	47	42
Ore.	2.95	23.34	23.51		4	42
\bar{x}	4.68	26.38	23.67	13.37	41.87	42.87
Sd	3.12	9.30	6.74	9.41	5.76	4.95

<u>Stage 2</u>						
<u>Subject</u>	<u>Percentages</u>			<u>Occurrences</u>		
	<u>BL</u>	<u>RS</u>	<u>SC</u>	<u>BL</u>	<u>RS</u>	<u>SC</u>
Avi.	0	10.3	10.6	0	15	19
Gid.	0	22.08	26.4	0	38	38
Ami.	0	21.6	21.1	0	37	35
Dan.	0	23.29	17.81	0	39	35
Ari.	0	13.95	15.3	0	16	19
Dav.	0	23.07	20.6	0	34	33
Ehu.	0	13.5	24.59	0	24	33
Ore.	0	23.49	26.1	0	26	35
\bar{x}	0	18.91	20.31	0	28.62	30.87
Sd	0	5.38	5.54	0	9.76	7.49

Table 1: Average percentages and occurrences of sleep stage 1 and 2 for each subject in the three parts of the study.

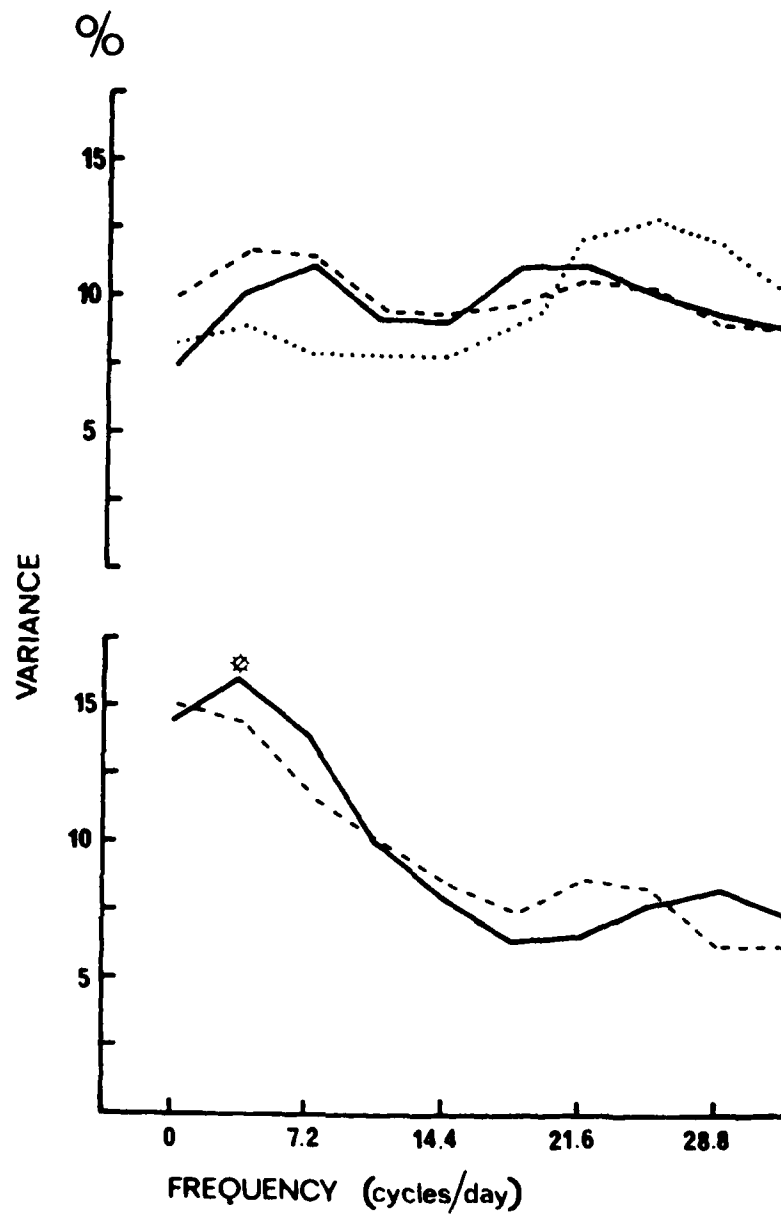


Fig. 3: Average spectra for stage 1 (upper panel) in the BL(....), RS(—) and SC(---) conditions, and for stage 2 (lower panel) in the RS(—) and SC (---) conditions. * Significant peak.

at frequencies of 7.2 c/d and 18-21.6 c/day, but neither peak approaches statistical significance. Average spectra for stage 2 in the RS condition significantly peaked at 3.6 c/d, corresponding to a dominant periodicity of about 360 min/cycle. Average spectra for stage 2 in the SC condition peaked at the zero frequency indicating a predominant linear trend in the data. In summary, spectral analysis confirms the existence of slow ultradian periodicity in the occurrence of sleep stage 2 in the RS condition. The periodicity was less evident in the SC experiment.

The slow ultradian rhythmicity in sleepiness was particularly striking in the data of the 4 subjects who were studied for 24 hours, again in the RS experiment. All subjects showed prominent slow rhythmicity in their amounts of total sleep and sleep stage 2; representative data are presented in Figs. 4A and B, which display the amounts of sleep stage 2 per 7 min for 2 of the 4 subjects. Both showed two diurnal peaks in sleep stage 2, at 0900-1000 and at 1600-1700, and a prominent nocturnal peak. Interestingly enough, in subject Da there was a monotonic decrease in sleep stage 2 toward the early morning hours, suggesting a dominant circadian effect.

Similar to the 8 subjects who were tested for 16 hours only, the rhythmicity in sleepiness in the SC experiment was less pronounced and more variable than in the RS condition. In all subjects, however, there was a clear nocturnal peak of sleepiness. Spectral analysis confirmed the visual impression by demonstrating a clear and significant spectral peak at 3.6 cycles/day in the RS condition. Corresponding to a periodicity close to 6 hour/cycle, no significant peaks were evident in the baseline or SC experiments for these four subjects.

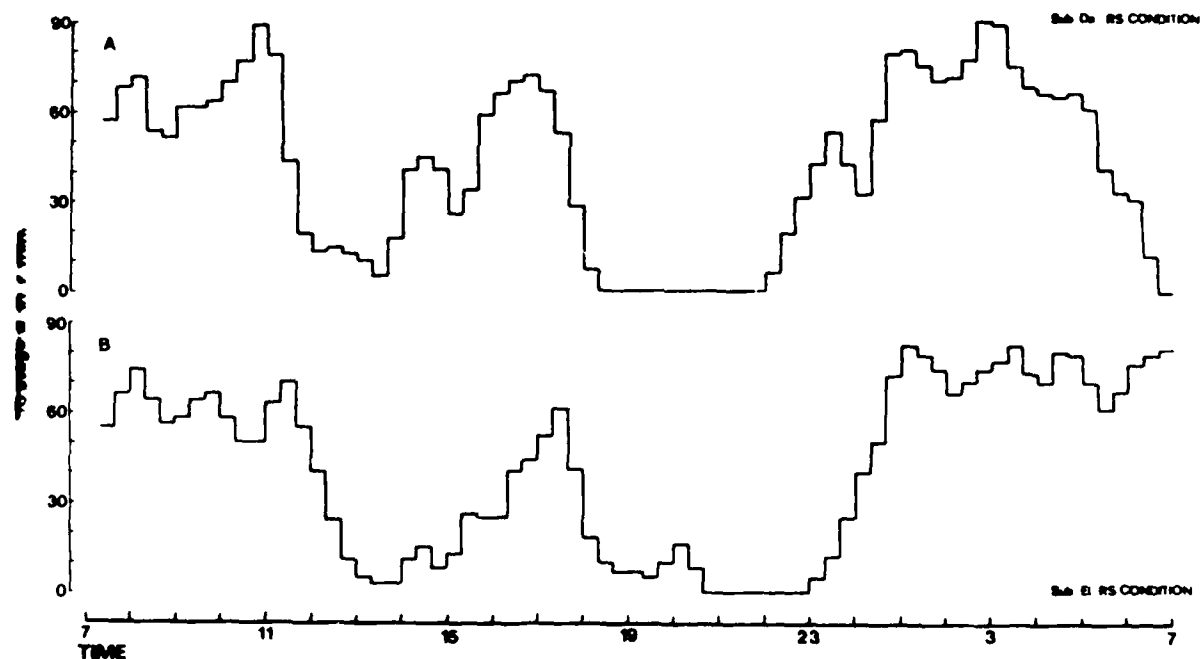


Fig. 4A & B: Slow ultradian cycles in the percentages of sleep stage 2 in two subjects tested for 24 hours. Please note the similarity between the two rhythms.

Reaction time task

The type of task utilized in the present study enabled the examination of ultradian rhythmicity in several aspects of performance, separately. First, the effects of sleep deprivation and ultradian rhythmicity on reaction time and movement time could be examined. Based on our previous findings (Lavie et al. 1981), we anticipated ultradian variations in movement time but not in reaction time. Second, since in each of the 20-min sessions, both simple tasks (one hand reactions) and complex tasks (disparate two-handed reactions) were presented, the interaction between sleep deprivation and ultradian rhythmicity, and task complexity and difficulty, could therefore be examined. In this report we will focus on the rhythmicity in performance of selected combinations and the interaction of this rhythmicity with the rhythms in sleep.

Reaction time and movement time

There was a marked difference between the temporal structure of the reaction time and movement time across the 24-hour experimental periods. In most subjects reaction times were stable, with minimal deviations from the mean level. In some test periods there was a linear increase in reaction time, which was particularly evident in the 4 subjects tested for 24 hours. Figure 5A, B & C present the reaction time data of one subject (pooled across all 5 combinations or across all 20 trials in each session) for the baseline, RS and SC experiments. Spectral analysis confirms the lack of significant rhythmicity in the reaction times. Furthermore, the complexity of the task did not affect the temporal structure of the data, although preliminary analysis revealed some effects of the task complexity on the overall mean reaction time.

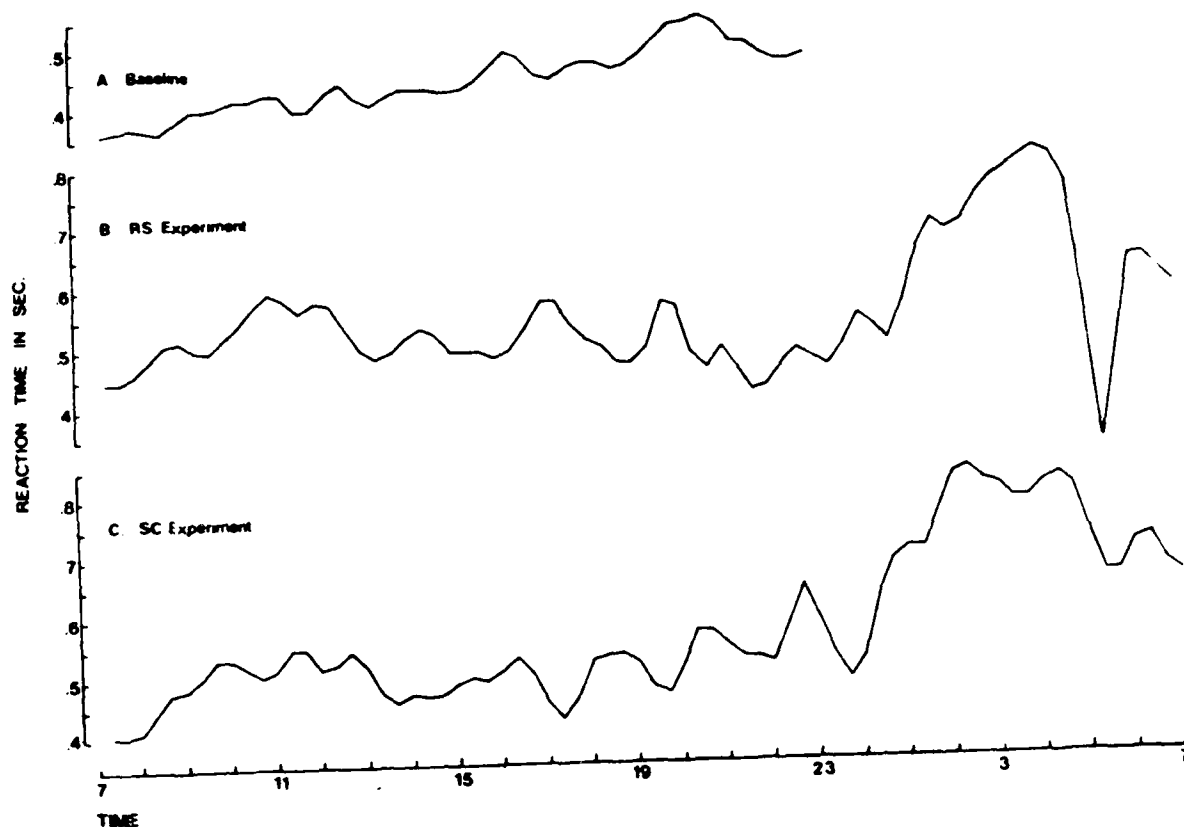


Fig. 5A, B & C. Reaction time data of one subject in the three parts of the experiment. Spectral analysis did not reveal significant rhythmicity besides the nocturnal increase in reaction time.

In a marked contrast to the stability of the reaction time performance, there were clear slow ultradian variations in movement time, particularly in the RS experiment, that correspond to the variations in arousal. Figures 6A, B and C present the movement time data of the same subject whose data for RT are shown in Fig. 5 for the one hand ("far" right condition), the left hand in the disparate two-handed condition, and for the average movement time for all conditions (N=20). The rhythmicity in the data is clearly seen in all three combinations. Peak movement times (which correspond to decrease in performance) occurred at 1100, 1720 and at 0420. Comparison of Figs. 6A and 6B revealed that the rhythmicity in movement time was more pronounced in the performance of the left hand in the two-handed disparate condition, than in the one-hand condition; the corresponding coefficients of variation (standard deviation/mean x 100) were 46% and 34%, respectively. The same rhythmicity was shown in the RS experiment by most of the subjects. Fig. 6D presents the average movement time for another subject investigated for 24 hours. This subject showed peak movement times at 1120, 16-1700 and 0300.

Correlating the sleep data with the movement time data clearly revealed that peak movement times coincided with peak sleepiness. This is clearly evident from comparing Fig. 4 and Figs. 6ABC and D which present the sleep data and movement time data of the same subject. Obviously the cycles are synchronized with each other.

The rhythms in movement time were less obvious in the SC experiment. Figs. 7A and 7B present the average movement time in the SC experiment for the same subjects whose data in the RS condition were presented in Figs. 6ABC and 6D. The variations in performance are clearly less regular and there is no phase relationship between the two curves, except for the common decrease in performance during the night time.

Spectral analysis, cross-spectral phase angle analysis are presently

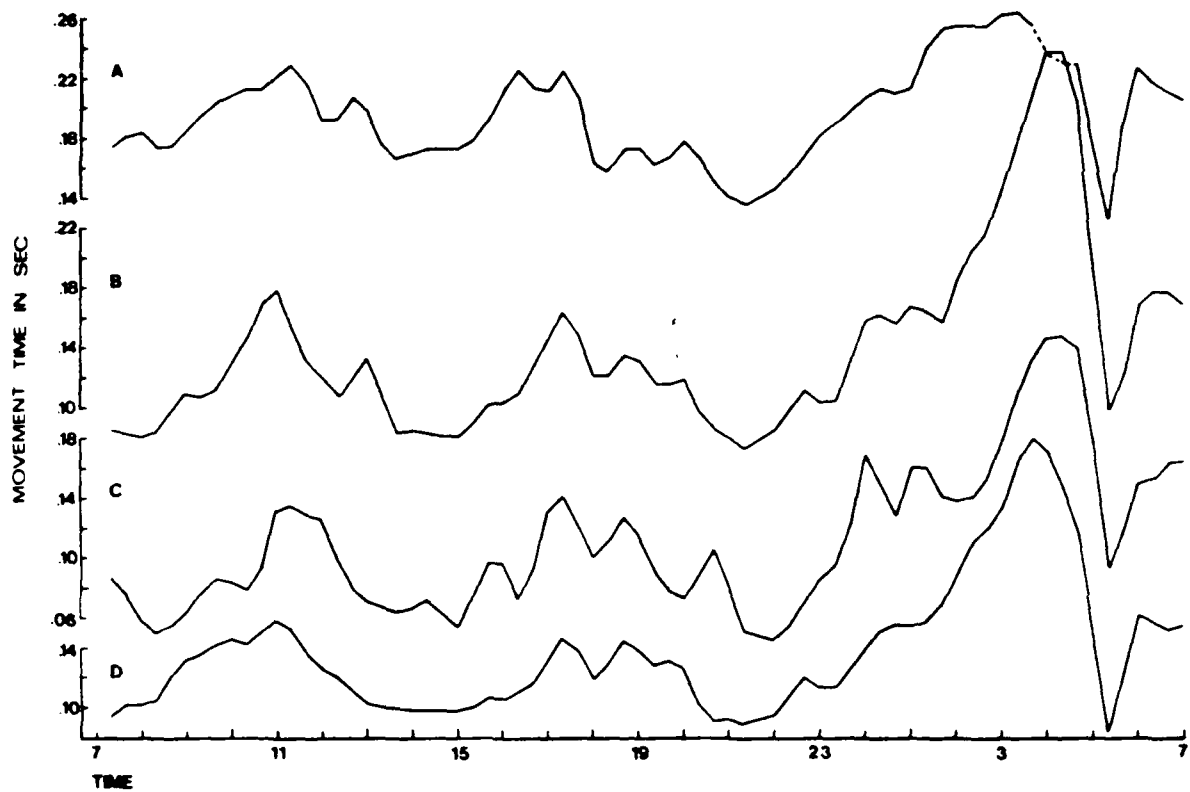


Fig. 6AB & C: Slow ultradian rhythms in movement time of the right hand in the "far right" condition (A), the left hand in the disparate two-handed condition, (B), and in the mean performance of all conditions pooled together (C).

Fig. 6D: Slow ultradian cycles in the mean movement time of another subject. Please note the similarity between the cycles in 6AB & C and 6D.

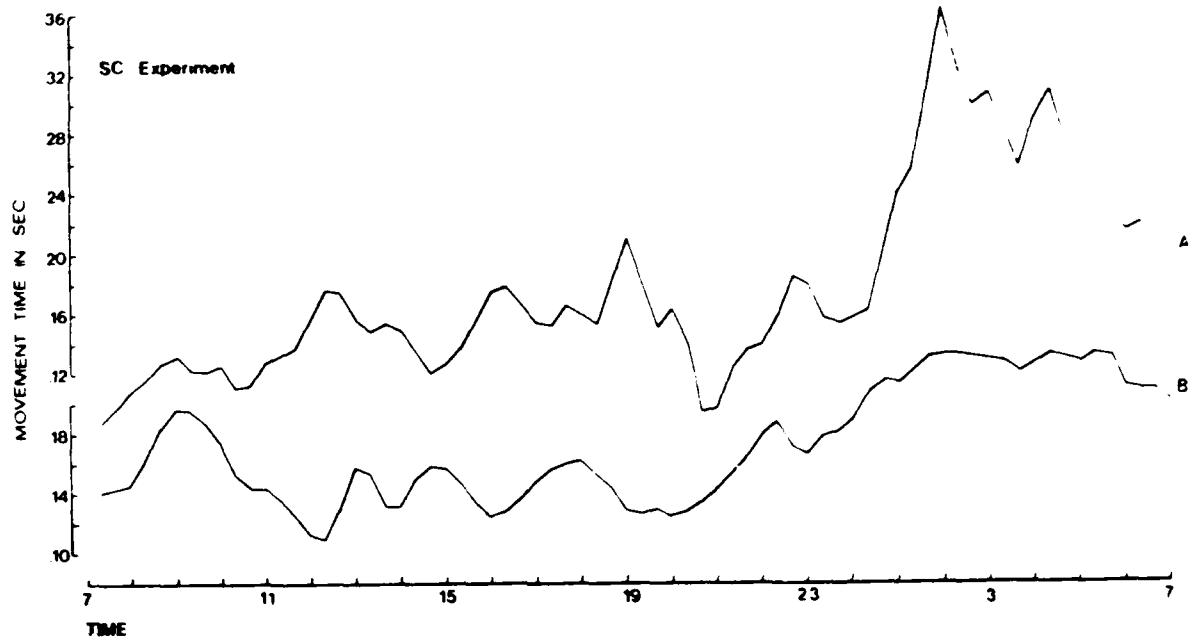


Fig. 7A & B. Mean movement times (pooled across all trials) for two subjects in the SC condition. The data of 7A correspond to 6ABC, and the data of 7B correspond to the data of 6D.

performed to determine the dominant periodicities in performance and the phase relationship between performance and arousal levels.

Performance - "Add 7"

There was a very marked practice effect from baseline to the first sleep deprivation experiment but there was no significant difference between SC and RS in the overall performance levels. The means were 6.23, 6.2, and 9.46 for baseline, SC and RS respectively. Spectral analysis did not reveal any consistent spectral peaks in any of the experiments.

Discussion

The results of the present studies clearly confirm our prediction that under sleep deprivation conditions the fast ultradian rhythmicity in sleepiness is modified toward a slow rhythmicity. Such 4-6 hour rhythmicity during the daytime hours was clearly evident in the RS experiment, which was most dramatically evident in the 4 subjects investigated for 24 consecutive hours. Clearly the rhythmicity in arousal affects performance; the variations in movement time, but not in reaction time or in the "add 7" performance, were synchronized with the amounts of sleep. The independence of the reaction time performance and calculation performance from the rhythms in sleepiness support our previous conclusion that the ultradian rhythms in arousal affect only some aspects of performance, which are probably related to short term memory processes and selective attention (Gopher & Lavie, 1980).

The difference between the RS and SC experiments was rather interesting and to some extent even unexpected. In spite of the fact that there was no significant difference between the two experiments with respect to the overall amounts of sleep stage 1 and 2, there was a phase difference between

the respective sleepiness curves. In the SC experiment the first peak in sleepiness appeared 1 hour earlier than in the RS experiment. However, even more interesting, comparing the data of the 4 subjects investigated for 24 hours to the data of the 8 subjects investigated for 16 hours suggest that the length of the experiment clearly affects the temporal structure of the vigilance stages across the day. In the 24-hour experiment there was a marked suppression of the slow ultradian rhythmicity as compared with the ^{16h}SC experiment. This clearly suggests that knowledge about the length of the sleep deprivation period, and subjects motivation (to remain awake, or to fall asleep) can drastically modify the structure of daytime vigilance stages. This last conclusion has both theoretical and practical implications. One of the immediate recommendations, based on the present results, is that recuperative naps following sleep deprivation should be spaced 5-6 hours apart. Furthermore, it appears that 1100h and 1700h are the appropriate "windows" for such naps. Optimal timing of recuperative naps should take into consideration the endogenous cycles in vigilance curves. Also, it appears that providing accurate information about the length of the expected sleep deprivation appears to be important for the prediction of the prospective "deeps" in arousal, or the appearance of irresistible sleep periods. The clearest and most regular cycles appear when subjects were investigated for 24 hours and were required to resist sleep. The cycles were considerably less clear when they were given 7 -min sleep attempts.

In recent years, there has been a great interest in the question of what are the optimal times for sleep. It has been shown, for instance, that sleep during the descending portion of the temperature cycle is longer than sleep during the ascending portion of the cycle (Wever, 1979). In spite of the general agreement that napping has beneficial effects in preventing some of the long term deterioration of performance during sleep deprivation, little is known about the optimal timing of such recuperative naps. This question appears highly important in light of the observations that immediate performance upon awakening from a nap may show no improvement and furthermore, may be even lower than the pre-nap levels. Langdon and Hartman (1961) were the first to demonstrate loss of performance efficiency after sudden awakening from nocturnal sleep. The post-awakening sleep inertia is usually short-lasting and has been estimated to last about 15 min (Wilkinson & Stretton, 1971). It is quite possible, then, that a recuperative nap, taken at the wrong biological time, may cause a more severe and longer period of sleep inertia, making the nap disadvantageous for behavioral efficiency. Preliminary support for the dependence of the length and severity of sleep inertia on the timing of the nap was provided by Naitoh (1981). He showed that the recuperative power of naps taken at the early morning hours (0400-0600) was considerably lower than the recuperative power of a midday nap (1200-1400). Further than that, Naitoh concluded that one 2-hour midday nap, taken after 53 hours of wakefulness, was as recuperative as the combined action of two 2-hour naps taken during the early morning hours and midday, after a shorter period of wakefulness. The reason for the lower recuperative power of the early morning nap was the long and more severe post-nap sleep inertia.

We found significant slow ultradians only in the RS study.

It has been widely accepted that increased motivation tends to counter-affect decrement in performance due to sleep loss, and to minimize circadian variations in performance. Wilkinson, (1961) & Blake, (1971) demonstrated that the variation in performance over the day of a letter cancellation task is dramatically reduced by an incentive. This was provided by giving subjects immediate knowledge of results, after each test session, in the presence of all members of the group. The resultant heightened state of motivation in the group dramatically reduced the magnitude of the diurnal variations in performance. Chiles, Alluisi and Adams (1968) have also demonstrated this "dampening" effect of raised motivation on the amplitude of circadian performance variation. Gopher & Lavie (1981) demonstrated similar effects with respect to ultradian rhythmicity. Immediate knowledge of results suppressed the 14.4 c/day ultradian rhythmicity in a perceptual motor task.

In light of this dampening effect, in the present study increased motivation had an opposite effect. It emphasized and consolidated the slow ultradian rhythmicity in sleepiness and performance. The 360 min periodicity in sleepiness was significant only in the SR condition, where subjects were promised monetary rewards if they managed to stay awake.

A militarily realistic regime is one which demands several days of continuous activity, followed by a period of less intense activity, during which short periods of rest may be possible. Haslam (1981) demonstrated that even small amounts of scheduled sleep are beneficial to military personnel involved in continuous performance. That is, sleep loss effects over prolonged periods of sleep deprivation can be minimized by offering limited amounts of sleep. The question now is how much sleep and at what time.

Our present results demonstrated that during the habitual waking hours there were two periods of irresistible sleep: at 8-11 and 16-18 hours. On the other hand, sleep could easily be avoided at 12-14 and 19-22. Therefore, one can predict that the recuperative power of naps taken at 9 and 17 will be greater than the recuperative power of naps taken at 13 or 20. Hence our study for the first time provides some guidelines for determining the optimal timing for daytime naps.

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